Reconfigurable Leaky Wave Antennas

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***Abstract*—An overview of reconfigurable leaky wave antennas is presented. A systematic study on reconfigurable Fabry Pérot leaky wave antennas is described. The progress made in recent years is demonstrated by a number of configurations and the associated experimental results.**

***Index Terms*—Reconfigurable Leaky Wave Antennas, Fabry Pérot Antennas, Frequency Tuning, Scanning.**

I. INTRODUCTION

Leaky Wave Antennas can be regarded as transmission lines that gradually leak the energy out into free space. The direction in which the energy is radiated from a leaky wave antenna, θ, is determined by the phase constant, β, of the leaky wave along the transmission line [1], as shown in Fig. 1. The beamwidth of a leaky wave antenna is determined by the length of the leaky aperture, which must be illuminated by proper control over the leakage rate α [1].

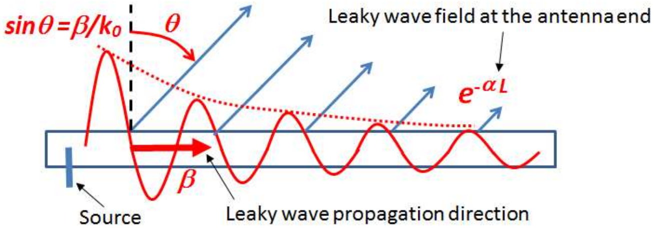


Fig. 1. Scheme of a leaky wave antenna.

The concept of leaky-wave antennas has been around for decades [1, 2]. Compared with reflector and lens antennas, it has the advantage that no protruding feed is needed so the antenna can have a very low profile. Compared with array antennas, it does not need a feeding network which can become very lossy for large arrays. The phase constant of a leaky wave antenna is typically a function of the operating frequency, and this fact can be used to steer the beam direction by sweeping the operating frequency.

In the last decade, we have witnessed the fastest growth of the wireless communications industry and a multitude of wireless communications system standards. Wireless communication systems normally operate in a given frequency band defined by the spectrum regulators. Therefore, the inherent frequency scanning nature of leaky wave antennas has very limited use. To this end, there is a great need to develop pattern reconfigurable (beam-steering) leaky wave antennas which can be used to exploit the complexity of the propagation channel. Furthermore, leaky wave antennas have relatively narrow bandwidth, typically of only a few percent. However, given that wireless communications systems do not need a *simultaneous* wide bandwidth, a frequency reconfigurable (tunable) leaky wave antenna would serve as a good candidate for many applications.

This paper aims to provide an overview of the development of reconfigurable leaky wave antennas. Following the introduction, various attempts to developing reconfigurable leaky wave antennas are reviewed. Then we will introduce the reconfigurable leaky wave antennas developed at CSIRO, Australia, and Technical University of Cartagena, Spain.

II. A BRIEF HISTORY OF RECONFIGURABLE LEAKY WAVE ANTENNAS

The frequency-dependent nature of leaky wave antennas has limited their applications in modern communication systems, which generally require fixed frequency operation for effective channelization. In the past, significant efforts have been directed toward developing frequency-independent leaky wave antennas. Horn *et al.* [3] used PIN diodes as switches and electrically changed the radiation angle by controlling the guided wavelength. In their approach, however, only two discrete radiation angles were present because diodes have only two states, namely biased and unbiased. Maheri *et al.* [4] reported a magnetically scannable leaky-wave antenna built on a ferrite slab structure, in which the radiation angle is scanned by tuning the DC magnetic field. In [5], Huang *et al.* applied PIN diodes as switches to control the period of the structure, and the reconfigurability was limited to two discrete radiation angles.

In [6], Sievenpiper employed a high impedance surface which he called a textured surface to develop a leaky wave antenna which can scan from backward to forward directions from -50deg to 50deg. In the design, varactor diodes incorporated into the structure allow electronic control of the reflection phase and the surface wave properties. This tunable textured surface is then used as an electronically steerable leaky wave antenna by coupling energy into a leaky wave band using a flared-notch antenna. The textured surface consists of a periodic lattice of small mushroom-shaped protrusions made of square metal plates, connected to a common ground plane by vertical metal pins. These pins are alternatively connected to and protruded through the ground-plane to allow the controlling voltage to be applied. The square plates are all connected to each other with varactor diodes. By exploiting multiple degrees of freedom which the surface geometry provided, the authors achieved independent control of the magnitude and phase of the surface wave radiation, so the antenna can be programmed to have a large effective aperture over the entire scan range.

Left-handed (LH) materials characterised by simultaneously negative permittivity and permeability were introduced theoretically by Veselago [7] and investigated experimentally by Shelby *et al.* [8]. The propagation constant of a left-handed material is negative, representing a phase advance, whereas that of a right handed material is positive, representing a phase lag. Combining structures with LH and RH contributions results in a composite RH-LH (CRLH) structure, which can be used to realize both forward and backward scanning. This concept was first introduced using a transmission line structure in [9]. In [10], a metamaterial-based electronically controlled transmission line structure incorporating varactor diodes was proposed as a leaky-wave antenna with tunable radiation angle and beamwidth functionalities. This structure is, in essence, a composite right/left-handed (CRLH) microstrip structure incorporating varactor diodes for fixed-frequency voltage-controlled operation. Angle scanning at a fixed frequency is achieved by modulating the capacitances of the structure by adjusting a uniform bias voltage applied to the varactors. Beamwidth tuning is obtained by making the structure nonuniform by the application of a nonuniform bias voltage distribution of the varactors. A 30-cell leaky wave antenna structure, incorporating both series and shunt varactors for optimal impedance matching and maximal tuning range, is designed. This prototype exhibits continuous scanning capability from +50deg to -49deg by tuning the bias voltages from 0 to 21 V at 3.33 GHz. A maximum gain of 18 dBi at broadside is achieved, but the gain variation with scan angle is large. In addition, it provides half-power beamwidth variation of up to 200% with comparison to the case of uniform biasing.

Employing tunable partially reflective surfaces and high impedance surfaces in Fabry-Pérot structures proved to be another way of achieving frequency reconfigurability and pattern reconfigurability in leaky wave antennas effectively. The authors have conducted a systematic study in this regard in recent years which will be presented in the following sections.

III. FREQUENCY RECONFIGURABLE FABRY PÉROT ANTENNA

Fabry-Pérot leaky wave antennas have the advantages of low profile, simple construction and high directivity. They are created by placing a partially reflective surface (PRS) around half a wavelength above a ground plane containing a low directivity source antenna [11]-[15]. The PRS is usually a periodic array of dipoles, patches or slots on a dielectric substrate. If the ground plane is replaced with a high impedance surface (HIS) the profile of the antenna can be significantly reduced [13-14]. A significant drawback of the Fabry-Pérot leaky wave antenna is the narrow operating bandwidth, due to the high Q factor of the Fabry Pérot cavity. However the utility can be improved by making the operating frequency reconfigurable, through the use of a tunable HIS on the lower surface of the cavity where each cell of the HIS is tuned through the voltage applied to a pair of varactor diodes [16],[17].

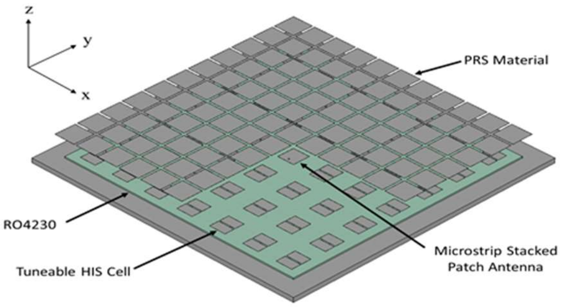


Fig. 2. Geometry of the frequency reconfigurable FP LWA.

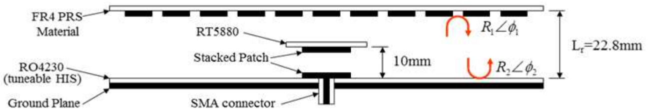


Fig. 3. Schematic of the frequency reconfigurable FP LWA showing reflection coefficients of the PRS and HIS.

The geometry of the Fabry-Pérot leaky wave antenna, comprising a PRS, tunable HIS and stacked patch feed antenna, is shown in Fig. 2 [15]. Its operating frequency was designed to be tuned from 5.2GHz to 5.775GHz to enable use in WLAN applications. Referring to Fig. 3, the cavity height L_r may be expressed in terms of the operating wavelength λ_0, and the reflection phase of the PRS ($R_1\angle\phi_1$) and tunable HIS ($R_2\angle\phi_2$) as follows [14].

$$L_r = \left(\frac{\phi_1 + \phi_2}{\pi}\right)\frac{\lambda_0}{4} + \frac{\lambda_0}{2} \tag{3}$$

Since ϕ_2 is a function of the varactor tuning voltage, it is possible to reconfigure the operating frequency of the antenna. Increasing the tuning voltage gives an increase in the antenna resonant frequency, while lowering the voltage reduces the resonant frequency. In this implementation the PRS is made from 18x18mm square metallic patches placed on a 0.8mm thick FR4 substrate (ε_r=4.4, tan δ=0.018), with a periodicity of 20mm in both x- and y-directions. A total of 48 tunable HIS cells are used on a 1.524mm thick Rogers RO4230 substrate (ε_r=3.0, tan δ=0.0023). Patch dimensions are 14mm by 17mm, with a 1mm air gap between its two halves for placement of the varactor diode pair. Both substrates have lateral dimensions of 240mm by 240mm. A stacked probe-fed patch was chosen for the source because simulations showed it gave better matching as the HIS surface was tuned, compared to a single patch.

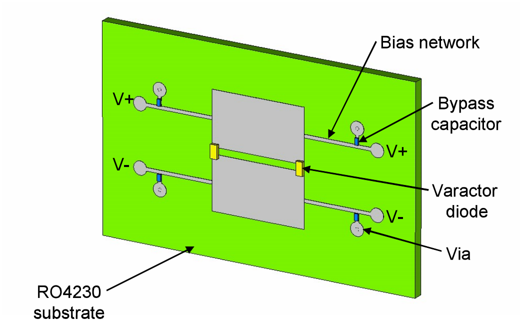


Fig. 4. Geometry of the tunable HIS unit cell.

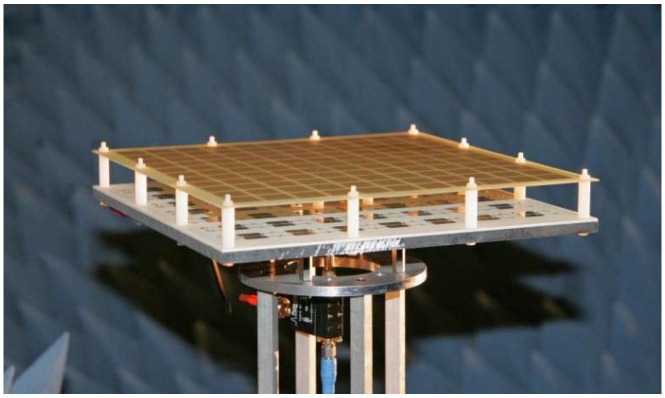


Fig. 5. Photograph of the frequency reconfigurable FP LWA prototype.

Fig. 4 depicts the geometry of the tunable HIS cell used in the antenna, and includes the bias network which consists of 0.5mm wide high impedance lines, 2.2pF bypass capacitors and vias. The tunable HIS cell is based on a design from [16], used in a reconfigurable reflectarray [17]. However, it has been modified to include a distributed element bias network to allow simultaneous biasing of a complete row of tunable HIS cells. A photograph of the fabricated prototype antenna is shown in Fig. 5. Various nylon spacers have been used to position the PRS above the tunable HIS, and the coupled patch above the driven patch. A low-loss bias tee, which may be observed behind the antenna, is used to provide the bias voltage to the tunable HIS cells, and thus reconfigure the antenna's operating frequency. The varactor diodes used in the prototype were also "matched" by the manufacturer to ensure variations between the devices were as small as possible. The measured directivity versus frequency is plotted in Fig. 6 for six different bias voltages, which correspond to six different junction capacitances of the varactor diode. It is clear from Fig. 6 that the measured operating frequency tunes from 5.2 to 5.95GHz. The measured reflection coefficient of the antenna is shown in Fig. 7 and tracks the directivity peaks of Fig. 6 for the corresponding six bias voltages.

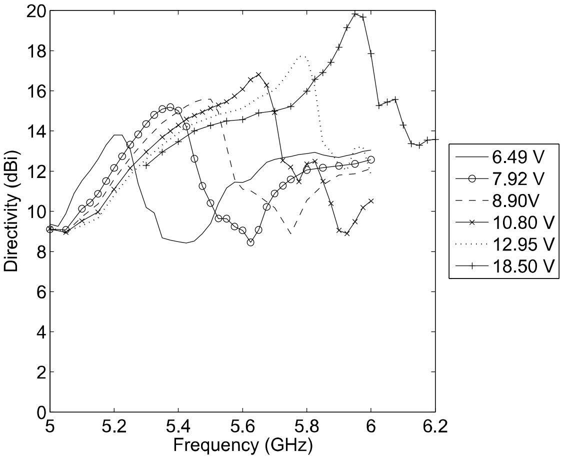


Fig. 6. Measured directivity of the frequency reconfigurable FP LWA for six different bias voltages.

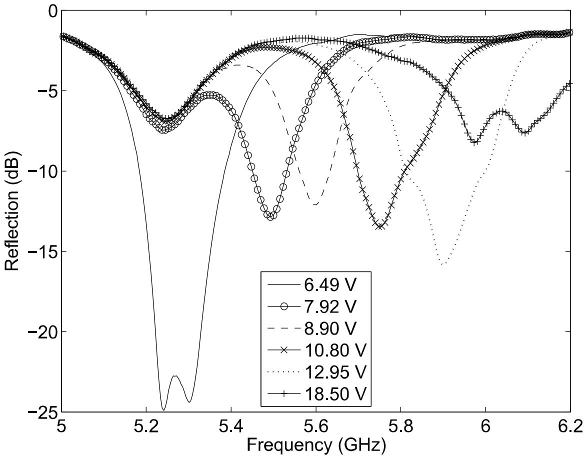


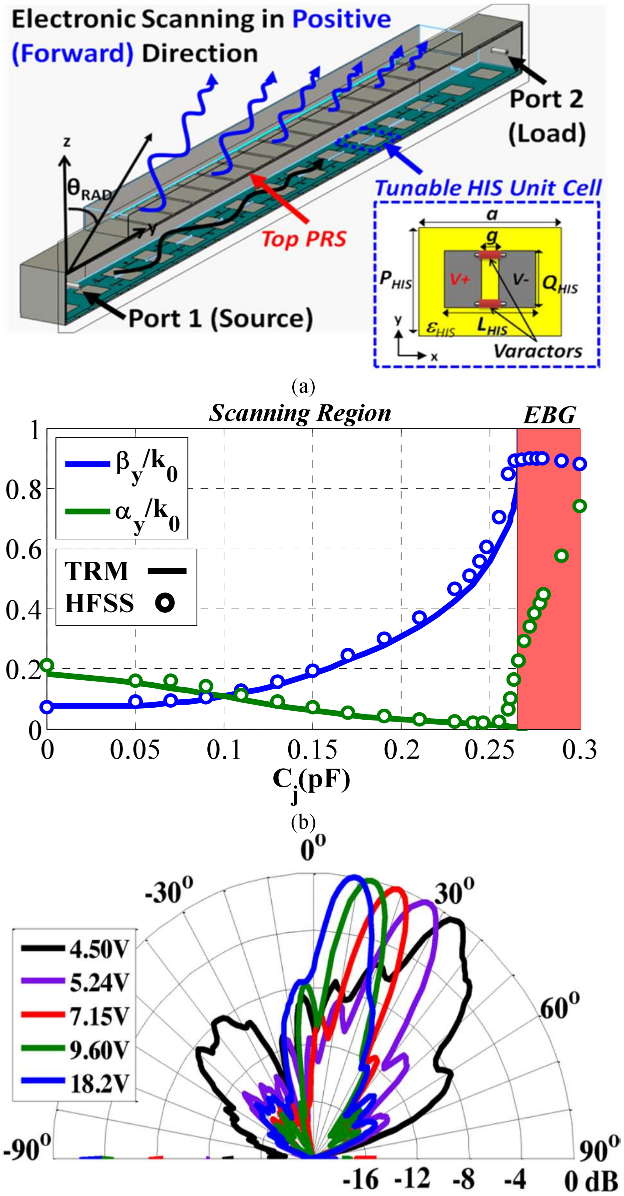
Fig. 7. Measured reflection coefficient of the frequency reconfigurable FP LWA for six different bias voltages.

IV. PATTERN RECONFIGURABLE LEAKY WAVE ANTENNAS

As mentioned earlier, one of the disadvantages of leaky wave antennas is that the radiation beam typically scans with the operating frequency. This is often problematic as, for many applications, it is required to have a fixed frequency band when the antenna beam is scanned. With one dimensional leaky wave antennas, this can be done by electronically reconfiguring the leaky-line boundary condition. Using active devices such as varactor diodes or MEMS, the leaky-mode complex propagation constant can be altered, thus producing the desired control of the scanning beam. Using the Fabry-Pérot structure, we have developed a number of techniques to scan the beam of a leaky-wave antenna at a fixed frequency.

A. Half-space scanning 1D Fabry-Pérot leaky wave antenna

As the first step, a one-dimensional half-space scanning leaky wave antenna is designed, as shown in Fig.8-a. This structure is inspired by the passive 1D Fabry-Pérot leaky wave antenna presented in [18], where a Fabry-Pérot cavity made of a top partially reflective surface (PRS) and a bottom high impedance surface (HIS) enable control of the leakage rate (α) and the phase constant (β) of the leaky mode through design of the physical length of the resonant patches. In this case, our structure provides electronic scanning of the main beam in the forward quadrant, at a fixed operating frequency [19], by replacing the passive HIS of [18] by a bottom tunable high impedance surface (HIS) loaded with varactor diodes [19]. Now, the β of the leaky wave antenna can be controlled electronically as a function of the tunable junction capacitance (C_j) introduced by the varactor diodes which load the HIS patches (Fig.8-a) [15-17]. This C_j is tuned by the DC bias voltage (V_R) applied to the diodes.



(a)

(b)

(c)

Fig. 8. (a) Scheme of half-space scanning 1D FP LWA (b) Dispersion curves vs C_j and (c) Measured radiation patterns (H-plane) for different V_R at 5.5GHz.

The control of the LM dispersion with C_j is demonstrated in Fig.8-b, showing the normalized phase (β/k_0) and leakage (α/k_0) rates as a function of C_j for a fixed operating frequency of 5.5GHz, where k_0 is the free-space wave number in air. It is shown how the LM phase constant increases with C_j in the scanning region defined in the range C_j=[$0pF$,$0.27pF$]. As β/k_0 is related with the main beam radiation angle θ_{RAD} by $\sin(\theta_{RAD}) \approx \beta/k_0$ [1], a half-space electronic scanning of the fan beam direction with V_R is obtained in the positive quadrant from θ_{RAD}=+9° to θ_{RAD}=+34°, as experimentally confirmed by the measured radiation patterns shown in Fig.8-c.

B. Full-space scanning 1D Fabry-Pérot leaky wave antennas

The structure of a symmetrically-fed 1D Fabry-Pérot leaky wave antenna is depicted in Fig.9-a. This antenna is conceived to extend the half-space scanning range obtained from the previous 1D Fabry-Pérot leaky wave antenna design, to a full-space scanning range. This is achieved by taking advantage of the electromagnetic band-gap (EBG) property that is presented in the Fabry-Pérot cavity for low values of the tuning voltage V_R [20]. As shown in Fig.8-b, an EBG zone extends beyond the scanning region for C_j=[$0.27pF$,$0.3pF$]. LM propagation along the FP waveguide is prevented in this zone. A central coaxial probe-feed divides the original antenna in two symmetric leaky lines: LWA_{LEFT} and LWA_{RIGHT}. Each one is separately biased by V_L or V_R. Therefore, two leaky waves which are oppositely launched by the central coaxial feed yield two radiation patterns whose main beam pointing angles can be independently controlled based on the dispersion properties of the 1D Fabry-Pérot leaky wave antenna [19].

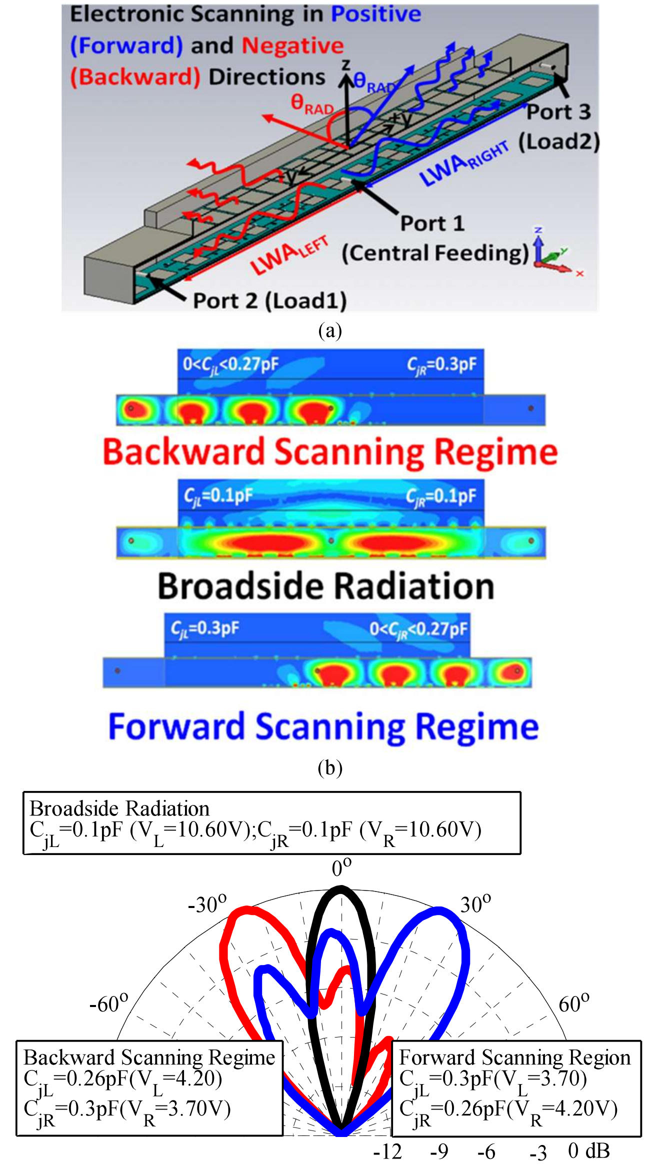
Using the scanning and EBG properties of the HIS-loaded Fabry-Pérot cavity, the leaky wave antenna can be electronically tuned to propagate/radiate energy or to serve as a reflector, depending on the electronic tuning of the HIS. Hence, the symmetrically-fed 1D Fabry-Pérot leaky wave antenna can be electronically tuned to operate in three different regimes:

1) Backward scanning regime (θ_{RAD}<0°): LWA_{LEFT} must be tuned inside the scanning region (C_{jL}<0.27pF) while LWA_{RIGHT} is fixed at EBG region (C_{jR}=0.3pF). In this way the input signal is guided to the left side of the LWA (no energy travels to the right side), providing scan at negative angles.

2) Forward scanning regime (θ_{RAD}>0°): This is the symmetrical case. LWA_{LEFT} is operated in the EBG regime (C_{jL}=0.3pF) and LWA_{RIGHT} is tuned in the scanning region to provide beam steering at positive angles (with C_{jR}<0.27pF).

3) Broadside radiation (θ_{RAD}=0°): Radiation at boresight can be obtained by launching two oppositely-directed leaky waves. To this end, LWA_{LEFT} and LWA_{RIGHT} are tuned at the same operating point inside the scanning region at or below the splitting condition β=α [21] (which is obtained for C_{jR}=C_{jL}=0.1pF in this case), so that the fields on the two sides of the antenna merge to form a single beam radiating at θ_{RAD}=0°.

For a better physical insight, the electric field distribution inside the Fabry-Pérot cavity is depicted in Fig.9-b for the three operating configurations, showing how the input energy can be routed to the right or left directions depending on the varactors' tuning voltage. Finally, measured radiation patterns of a fabricated prototype are shown in Fig.9-c, confirming full-space electronic scanning from -25° to +25° at 5.5GHz.



(a)

(b)

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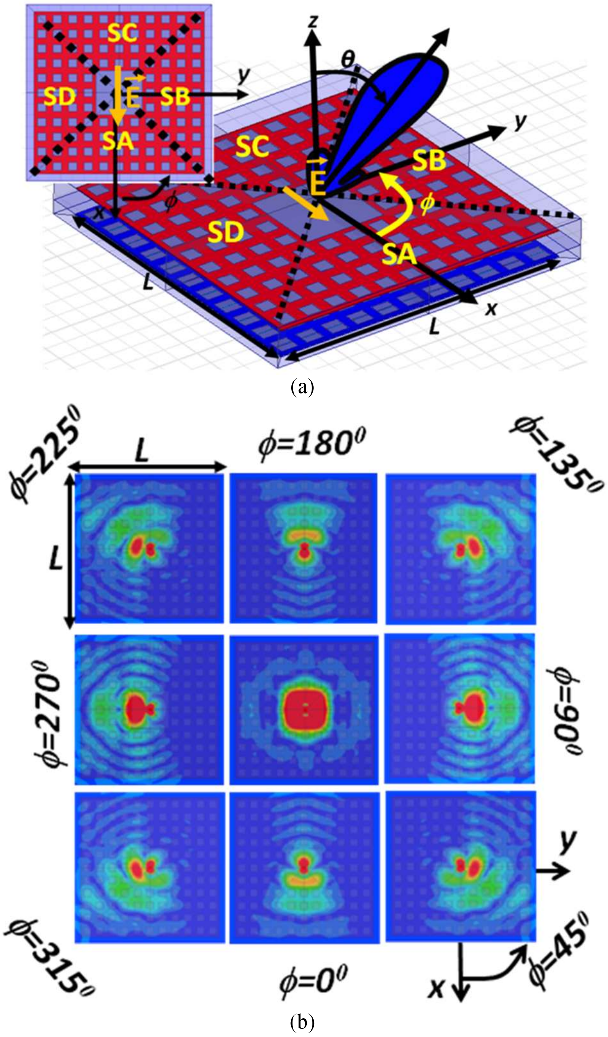
Fig. 9. (a) Scheme of full-space scanning 1D FP LWA (b) Electric field distribution along the 1D FP LWA structure and (c) Measured normalized radiation patterns (H-plane) at different operating regimes (5.5GHz).

C. *Full-space scanning 2D Fabry-Pérot leaky wave antennas*

The EBG routing and scanning concepts described earlier can be extended from 1D to 2D Fabry-Pérot leaky wave antennas, so that 2D electronic scanning (azimuth and elevation) is obtained without using phased-arrays [22]. As a proof of the concept, a 2D Fabry-Pérot antenna was designed using a 2D PRS at the top and 2D tunable HIS at the bottom. The varactors have been arranged into four independently biased azimuthal sectors (SA to SD, as shown in the scheme of Fig.10-a). In this case, a cylindrical LM is excited at the centre of the 2D Fabry-Pérot cavity by a horizontal dipole oriented along the *x* axis (Fig.10-a). This cylindrical LM is thus TM-polarized in sectors SA and SC (x-axis), TE-polarized in sectors SB and SD (y-axis), and a hybrid TE/TM LM for other directions [23]. As in the 1D case, the LM are routed towards a given sector by tuning it into the scanning region while the rest of the sectors are tuned to the EBG region.



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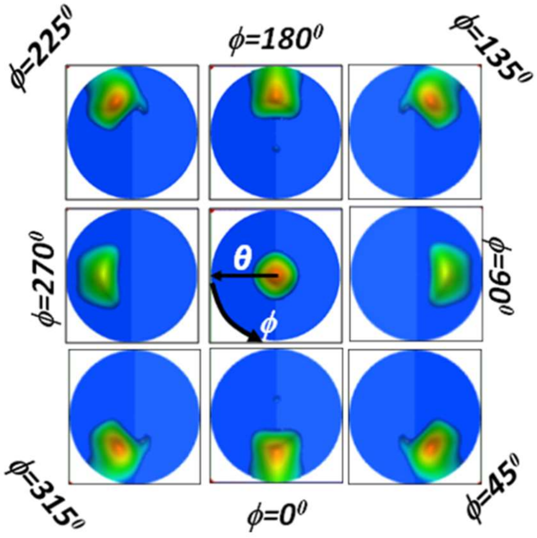

(c)

Fig. 10. Extension of the EBG routing mechanism for full-space electronic scanning in 2D FP LWAs: (a) HFSS 3D model of the tunable 2D FP (A=5.4λ0x5.4λ0), (b) Near fields inside the 2D FP cavity for several configurations of the sectors and (c) Radiation pattern in U-V coordinates (θ range represented [0º,45º]).

Therefore, pencil beams which are scanned in the elevation plane (θ_{RAD}) can be created for discrete azimuthal (ϕ_{RAD}) angles defined by the four sectors. As a result, four radiation regimes can be defined according to the direction of propagation of the wave:

1) Radiation by TM LM propagating along the $\pm x$ axis. SA or SC is active (tuned at the scanning region) while all other sectors are inactive (tuned at EBG region).

2) Radiation by TE LM propagating along the $\pm y$ axis. SB or SD is active and all other sectors are inactive.

3) Radiation by hybrid TE/TM LM propagating along the oblique directions when two adjacent sectors are active (configurations SA&SB, SB&SC, SC&SD or SD&SA) and the other two are tuned to the EBG region.

4) Broadside radiation. Optimal directive pencil beam radiating at boresight can be obtained when all the sectors are active and tuned at or below the splitting condition [21].

Four different configurations of the sectors are illustrated in Fig.10-b and Fig.10-c, showing the simulated near fields inside the 2D Fabry-Pérot cavity and their respective radiation patterns. From the guided fields depicted in Fig.10-b, it is observed how the antenna aperture illumination can be modified by changing the activation of the azimuthal sectors. These illuminations lead to the synthesis of radiated pencil beams which can be steered to discrete azimuthal angles ϕ_{RAD}= [0º, 45º, 90º, 135º, 180º, 225º, 270º, 315º]. This is demonstrated by the position of the pencil beam in the radiation patterns obtained in Fig.10-c for each sector configuration. Moreover, for any constant azimuthal angle ϕ_{RAD}, tuning of the elevation scanning angle in the range θ_{RAD} = [5º,25º] can be obtained, by properly tuning the active sector inside the scanning range. Finally, the broadside case is also obtained when the four sectors are tuned to (or below) the splitting condition, resulting in a cylindrical LM covering all sectors (Fig.10-b) and a pencil beam pointing at boresight (Fig.10-c).

From these results, it is demonstrated that continuous elevation scanning and discrete azimuthal sectorization can be electronically obtained. This requires accurate control of the dispersion properties of TE, TM and hybrid TE/TM cylindrical LMs.

D. Reconfigurable 1D SIW LWA

Reconfigurable LWAs can also be realised in substrate integrated waveguide (SIW), taking advantage of the planar, low cost, low loss, easy integration with planar circuits, and simple excitation properties of this technology [24]. Several reconfigurable LWAs have been proposed in the last decade using metamaterial CRLH microstrip leaky lines [9-10] in order to obtain electronic beam steering [9] or even beamshaping [10]. In this section, two structures are presented to operate at ISM frequency band (5.5GHz). The first one is a reconfigurable 1D antenna in SIW technology (1D SIW LWA), which is based on the non-reconfigurable static design presented in [25]. This design is modified to provide full reconfiguration of its radiation pattern (radiation angle and beamwidth) using two control lines. It must be highlighted that it is the first time that it is demonstrated simultaneous electronic reconfiguration over the scanning angle and the beamwidth, without using complicated metamaterial unit-cells [10]. The second structure is a radial array of SIW LWAs as originally proposed in [26]. The introduction of electronic reconfiguration in the 2D LWA provides electronic elevation scanning and azimuthal sectorization (as in the 2D FP LWA studied in the previous section), as well as electronic shaping of the pencil beam.

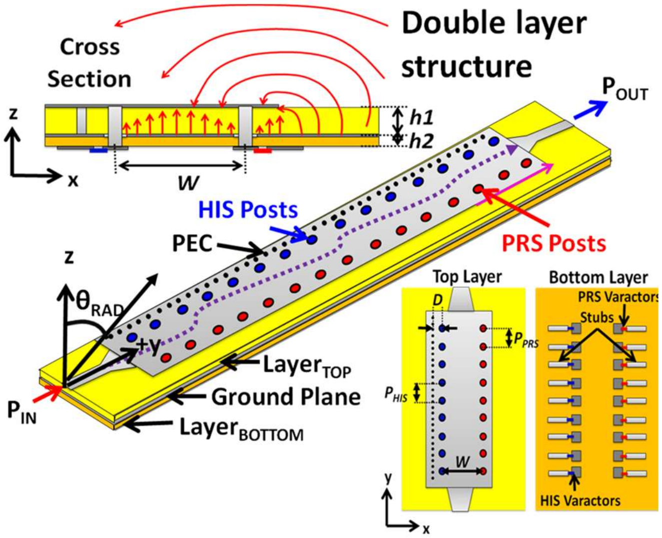

Fig. 11. Schematic of full-reconfigurable 1D SIW LWA: 3D model, cross section and front and rear views of the structure.

A schematic of the proposed full-reconfigurable 1D SIW LWA is presented in Fig.11. The antenna consists of a double-layer structure with a ground plane in between. The top layer holds the SIW, which is loaded with a tunable PRS and a tunable HIS in substrate integrated technology. Both PRS and HIS are SIW versions of the Fabry-Pérot sheets. They are made of arrays of metallic posts periodically arranged at a certain distance (called PRS posts and HIS posts in Fig.11). The PEC plane needed for the HIS is made of a dense arrangement of via-holes at a certain distance D from the HIS posts. Each post is connected by a through via to a varactor diode loaded in a microstrip stub, which is etched to the second layer (the control layer). Teflon substrates with ε_r=2.2 and thicknesses h_1=3.17mm and h_2=0.127mm are used for the radiation and control layers, respectively.

The PRS and HIS are separated by a distance W, comprising a resonant cavity that is analogous to the FP air-filled cavities of the antennas presented in the previous section, but in a substrate integrated technology. It is interesting to note that the radiation mechanism of this 1D SIW LWA is quite similar to the previous 1D FP LWA; according to the defined coordinate system, the FP antennas resonate between the PRS-HIS cavity, so the resonance is produced along the z-axis, whereas in the 1D SIW LWA case, this resonance arises along the x-axis. Moreover, in this case the PRS is also a tunable structure, so that it allows electronic control of the leakage rate (α) of the LM (which is related to the half-power beamwidth and directivity [1]). On the other hand, the tunable HIS controls the scanning angle by altering the LM phase constant (β), as described for the previous FP antennas. Both SIW PRS and HIS are independently biased, to enable independent and simultaneous electronic control of the radiation angle and beamwidth of the scanned fan beam.

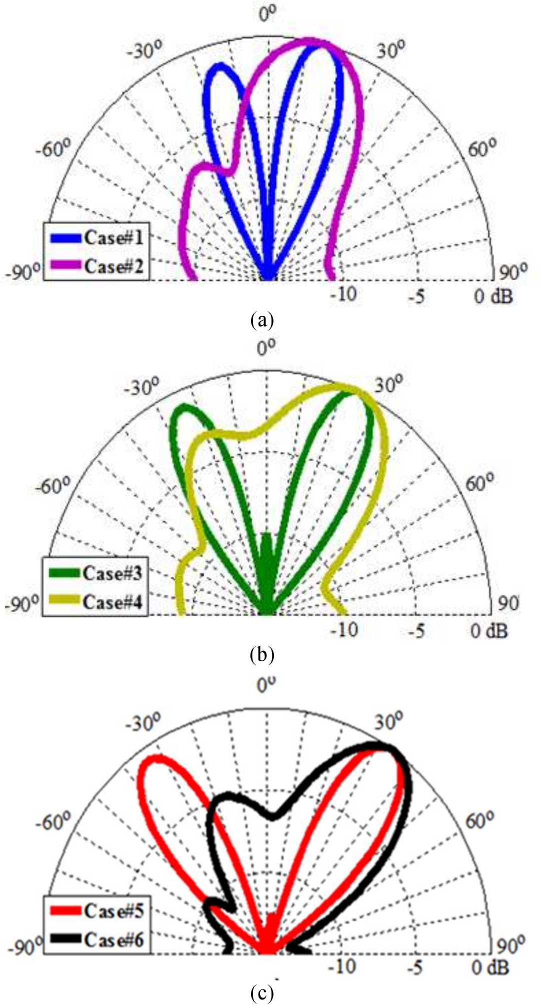

Fig. 12. Simulated radiation patterns (normalized directivity in dB) for different Cj_{HIS} & Cj_{PRS} configurations (5.5GHz): (a) Cases 1 and 2, (b) Cases 3 and 4, and (c) Cases 5 and 6.

A 1D SIW LWA has been simulated at a fixed frequency of 5.5GHz in order to demonstrate the concept. The antenna length is $L_A=3\lambda_0$, and it is terminated with a short-circuit load in order to estimate the variations in the leakage rate from the reflected lobe. The tuning parameters which reconfigure the antenna are the varactors' junction capacitances introduced at the HIS and the PRS circuits, C_{jHIS} and C_{jPRS} respectively. Simulated radiation patterns at 5.5GHz for six different configurations are presented in Fig.12. The values of the scanning angle (θ_{RAD}), the normalized attenuation constants (α/k_0), and associated -3dB beamwidth ($\Delta\theta$), are listed in Table I for each case. It is demonstrated that the scanning angle and the beamwidth can be simultaneously controlled by properly adjusting the two independently tunable parameters, namely C_{jHIS} and C_{jPRS}. Particularly, cases 1 and 2 show a beam scanned at $\theta_{RAD}\approx15°$ with variable beamwidths $\Delta\theta$=11° and $\Delta\theta$=36°, as it can be seen in the radiation patterns of Fig.12-a. The synthesis of narrow and broad beams is repeated for other scanning angles, namely $\theta_{RAD}\approx24°$ and $\theta_{RAD}\approx34°$, for cases 3-4 and 5-6, respectively. The normalized leakage rate is estimated for each case, by measuring the level between the main lobe and the mirrored reflected lobe [1]. As expected, narrow beams correspond to low leakage rates, while broader beams arise from increased leakage rate. A one-order-of-magnitude variation in α/k_0 is obtained for all scanning angles. To conclude, these preliminary simulations verify that the proposed tunable 1D SIW LWA allows flexible electronic tuning of the scanning angle and the directivity at a fixed frequency of 5.5GHz. Future work will provide a more detailed study of the dispersion curves of the antenna with C_{jPRS} and C_{jHIS}, and the optimal design and fabrication of a full prototype.

TABLE I

RESULTS FOR DIFFERENT COMBINATIONS OF C_{jHIS} AND C_{jPRS}

Case#	C_{jHIS}(pF)	C_{jPRS}(pF)	θ_{RAD}(deg)	α/k_0	$\Delta\theta$(deg)
1	0.45	0.2	15°	0.0036	11°
2	0.2	0.6	13°	0.0360	36°
3	0.5	0.2	24°	0.0017	13°
4	0.23	06	24°	0.0120	39°
5	0.6	0.2	34°	0.0009	16°
6	0.25	0.6	35°	0.0070	30°

E. Radial array of SIW LWA

Finally, these functionalities presented by the 1D SIW LWA are extended to azimuthal sectorization, with the purpose of obtaining electronic scanning in elevation and azimuthal planes, together with enhanced capabilities for electronic 2D beam shaping. To this aim, a radial array configuration of SIW LWAs simply fed by a central vertical coaxial probe [26] is proposed, as illustrated in Fig.13. Each azimuthal branch of the radial array is an independently controlled tunable 1D SIW LWA. As demonstrated in previous sections for the FP technology, the EBG routing concept allows selection of the azimuthal branch (or combination of branches) in which LM propagation is permitted (scanning region) or prohibited (EBG region). In this way, full-space electronic 3D scanning (in azimuth and elevation, including broadside), can be obtained using this radial-array electronically reconfigurable LWA in SIW technology.

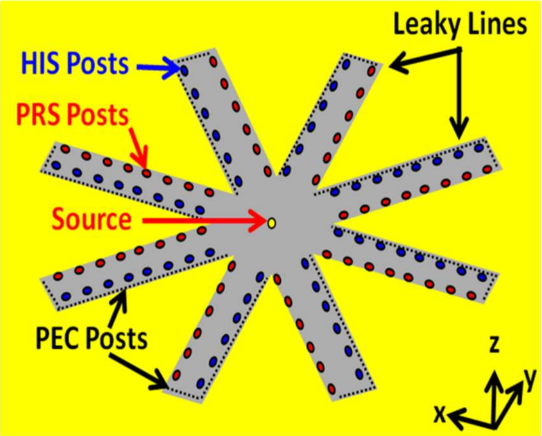

Fig. 13. Scheme of a radial array of reconfigurable SIW LWAs

Moreover, beam-shaping and control of the beamwidth / sidelobe level is achievable [27,28] by controlling the leakage rate for different scanning angles (tuning configurations). This flexible reconfigurable antenna opens a variety of novel real-time tapering designs [29] with multiple applications such as far-field beam forming [30], tunable near-field focusing [31], and electronically adjustable conformal antennas [32]. For the precise design of these antennas, holography-inspired synthesis techniques such as the one developed in [33] can be used. Therefore, this planar SIW topology seems to be a promising technology for low-cost simply-fed highly-directive electronic reconfigurable antenna applications.

V. CONCLUDING REMARKS

Research on leaky wave antennas has been going on for over half a century. In addition to some interesting electromagnetic phenomena, the advantages of low profile, simplicity and low cost of these antennas have fascinated many researchers around the world. Unfortunately, the disadvantages of simple leaky wave antennas, including narrow frequency and frequency dependent beam scanning, have kept them as academic research subjects chiefly and have prevented them from being used widely in industry. Inspired by the latest development of reconfigurable antennas and new electromagnetic structures such as EBG, partly reflective surfaces and meta-materials, reconfigurable leaky wave antennas are showing some very promising characteristics which can be exploited to provide novel solutions to applications in wireless communications and sensing. This paper is intended to present an overview of advances in the field, primarily made by the two groups in Australia and Spain. It is hoped that the reported work can stimulate further innovations in reconfigurable leaky wave antennas and facilitate their industrial adoption.

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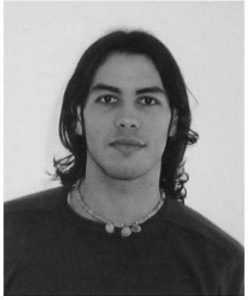

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Editorial Comment

Reconfigurablity, in general, appears to be an important future direction in antenna design, and in this article Guo addresses the problem of reconfiguring leaky wave antennas, which have been in the antenna scene for many decades. The availability of different types of reliable switches has made reconfigurablity considerably more practical for antennas than it was even a few years ago, making the antennas more flexible and enhancing the range of their applicability.
